

# <sup>10</sup>Be AND <sup>26</sup>Al PRODUCTION IN LUNAR ROCK 68815: REVISED PRODUCTION RATES USING NEW CROSS SECTION MEASUREMENTS.

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Radionuclide production in lunar rocks results from the interaction of both galactic (GCR) and solar (SCR) cosmic rays with all the elements in the rock's composition (1). The production of these cosmogenic radionuclides can be analyzed to give estimates of the solar proton flux over the past million years. Using information from several radionuclides and stable isotopes in the same rock allows constraints to be placed on the solar proton spectral parameters that can be used to interpret the measured data.

Measured production depth profiles for <sup>10</sup>Be ( $T_{1/2} = 1.5 \times 10^6$  yrs) (2), <sup>53</sup>Mn ( $T_{1/2} = 3.7 \times 10^6$  yrs) (3) and <sup>26</sup>Al ( $T_{1/2} = 7.05 \times 10^5$  yrs) (3) in lunar rock 68815 (by weight; 44.9% oxygen, 20.8% silicon, 15% aluminum, 11.1% calcium, 3.7% magnesium and 3.7% iron) have been reported (2,3). These three measured production depth profiles were analyzed using the Reedy and Arnold model (4) for several sets of solar proton spectral parameters. The <sup>10</sup>Be production cross section data set of Tuniz et al. (5) was used as input for the calculations of (2). This cross section data base contained estimated values for the relevant cross sections because few measurements had been made and the few that did exist were mainly at high proton energies.

While the <sup>53</sup>Mn and <sup>26</sup>Al profiles could be explained by several solar proton spectra with different spectral parameters, the very low SCR <sup>10</sup>Be production rate of ~1 dpm/kg

could be explained only by a solar proton spectrum that was much softer than that expected from other analyses made using other radionuclides (2,3). One possible explanation for this discrepancy was that the cross section values used as input to the theoretical calculations of the <sup>10</sup>Be production rate were wrong (2).

Since 1987, the work of this and other groups (e.g., 6,7,8,9) in measuring <sup>10</sup>Be production cross sections over a wide proton energy range has established good databases for most of the major elements of 68815. Figure 1 shows the present status of the cross sections  $O(p,x)^{10}\text{Be}$  with the 1984 data set (T4P) used in (2) and the current data set of 1997 (F7P). The wealth of recent cross section data allows us to use the data set F7P with confidence in theoretical calculations. Using F7P it is estimated that the reaction  $O(p,x)^{10}\text{Be}$  accounts for ~94% of the <sup>10</sup>Be production in the surface layer of 68815.

Figure 2 shows the <sup>10</sup>Be production rate calculated in 68815 using both cross section data sets for SCR parameters  $R_0 = 100$  MV,  $J_0 = 70$  p/cm<sup>2</sup> s ( $E > 10$  MeV,  $4\pi$  irradiation), and no erosion. As can be seen from Figure 2, now that the cross sections are well known, the predicted <sup>10</sup>Be production rate by solar protons is ~2.5, even greater than that predicted using the T4P cross section data set. This theoretical <sup>10</sup>Be production rate of ~2.5 dpm/kg is much larger than the measured production rate of ~1 dpm/kg and

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supports the other possible explanation given by (2) of a much softer solar proton spectrum over this time period in the past.

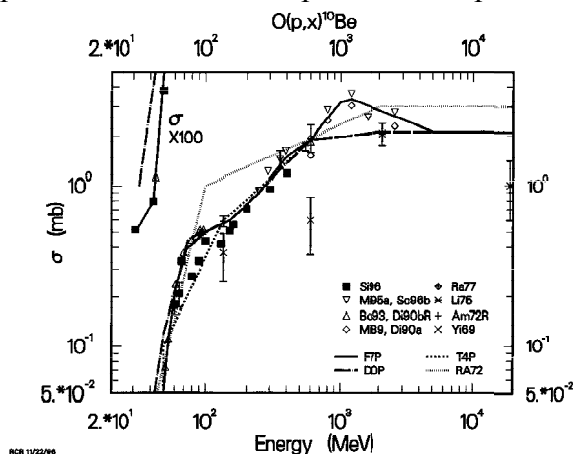


Fig 1. Cross section data set  $O(p,x)^{10}\text{Be}$

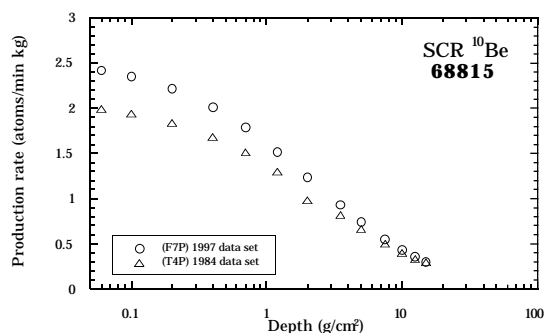


Figure 2.  $^{10}\text{Be}$  Production rate in 68815 ( $R_0=100$  MV,  $J_0=70$  p/cm $^2$  s ( $E>10$  MeV,  $4\pi$ )) for the cross-section data sets T4P (5) and F7P (this work)

The low  $^{10}\text{Be}$  measured in lunar rocks such as 68815 only constrains the incident solar-proton spectra. The solar-proton flux is determined from other nuclides, such as  $^{26}\text{Al}$ .

Much progress has been made in measuring cross sections for the production of  $^{26}\text{Al}$  from elements found in 68815. The last cross section data base for this radionuclide was compiled in 1987 (10). Figure 3 compares the SCR production rate of  $^{26}\text{Al}$  in 68815 using the data set R7P of (10) and that (S7P) compiled from recent measurements (6,7,8,9). Now that there are more reliable cross sections, the production rate in the surface layer has increased by

26%. The proton flux determined with  $^{26}\text{Al}$  thus will be less than those determined with earlier cross-sections sets (4, 10, 11).

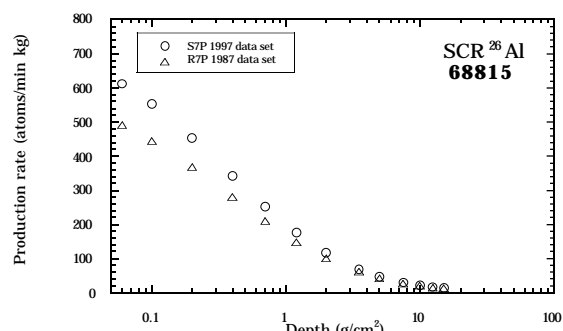


Figure 3.  $^{26}\text{Al}$  production rate in 68815 ( $R_0=100$  MV,  $J_0=70$  p/cm $^2$  s ( $E>10$  MeV,  $4\pi$ )) for the cross-section data sets R7P (10) and S7P (this work)

There are now good reliable cross section measurements for  $^{10}\text{Be}$  and  $^{26}\text{Al}$  production from the major constituents of lunar rocks. Using these good cross sections as input to calculations leads to estimates of the solar proton flux that can be used with confidence to study the sun's activity in the past.

In particular, using the new, good cross section data base for the production of  $^{10}\text{Be}$  in 68815, constrains the solar proton spectral parameters to support a softer solar proton flux over this time period in the past.

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